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Small U.S. dairy farms: can they compete?

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Abstract

The U.S. dairy industry is undergoing rapid structural change, evolving from a structure including many small farmers in the Upper Midwest and Northeast to one that includes very large farms in new production regions. Small farms are struggling to retain competitiveness via improved management and low-input systems. Using data from USDA's Agricultural Resource Management Survey, we determine the extent of U.S. conventional and pasture-based milk production during 2003–2007, and estimate net returns, scale efficiency, and technical efficiency associated with the systems across different operation sizes. We compare the financial performance of small conventional and pasture-based producers with one another and with large-scale producers. A stochastic production frontier is used to analyze performance over the period for conventional and pasture technologies identified using a binomial logit model. Large conventional farms generally outperformed smaller farms using most economic measures—technical efficiency, various profitability measures, and returns to scale.

JEL classification: Q12

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1. Introduction

As with most animal agricultural industries that involve intensive, confined animal feeding, large-scale U.S. dairy farmers face significant challenges as they deal with increased urbanization, consumer preferences that increasingly demand low-input (non-rBST, organic, pasture-based, etc.) milk, environmental restrictions, and others. In addition, an ideal American agriculture has traditionally been one where small farms could prosper, farmers experienced a great deal of autonomy in their everyday farm decision-making, and barriers to entry for new, beginning, and especially young farmers, were not prohibitively high.

It has been argued that one way these concerns can be partially addressed is through the use of small-scale pasture-based dairy operations, where animals are allowed to graze, reducing the quantity of manure accumulated in confined areas and potentially reducing odor problems. Though often characterized by lower milk production per cow, pasture-based operations are perceived to be more "natural" and environmentally friendly than are conventional systems. The purpose of this study is to determine whether small-scale U.S. dairies can compete in an industry that is increasingly characterized by large-scale firms. The alternative hypothesis is that they can compete, but their competitiveness will depend upon choice of production system. We compare efficiency and profitability of dairy farms among seven categories based upon size and system: Pasture-based <50 Cows, Conventional <50 Cows, Pasture-based 50–99 Cows, Conventional 50–99 Cows, Pasture-based ≥100 Cows, Conventional 100–499 Cows, Conventional 500–999 Cows, and Conventional ≥1,000 cows.

A thorough analysis of the impact of dairy farm size on competitiveness requires consideration of production system, as dairy farms vary widely in technology/system use. The largest U.S. dairies are generally "conventional dairies," conventional referring in this case to capital-intensive, high-input, high-output, confinement dairies that rely minimally on pasture grazing for animal nutrition. Pasture-based production, on the other hand, relies heavily on forage from pasture. Pasture-based systems are generally lower users of various technological innovations such as recombinant bovine somatotropin, computerized technologies, and others.

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An important reason for investigating the impact of system choice on competitiveness is that significant economies of size have been shown in dairy production. MacDonald et al. (2007) show the cost advantages associated with large-scale production using several methods. Mosheim and Lovell (2006), as well as Tauer and Mishra (2006), also show significant economies of size, both using USDA Agricultural Resource Management Survey (ARMS) data. Tauer and Mishra (2006) show that much of the lack of competitiveness of small dairy farms is due to inefficiency. These studies, however, have not fully considered system choice, such as whether a small, low-input pasture-based system can be competitive.

Using ARMS data for 2003–2007, this study compares the performance measures (scale and technical efficiency and return on assets) of various sizes of dairy operations depending upon their classification as pasture-based or conventional operations. Using these results, we then draw conclusions regarding competitiveness. We use the 2005 ARMS survey, dairy version, to predict system for the 2003–2007 ARMS Phase III because the 2005 ARMS survey, dairy version, asked questions on pasture usage that were not in the earlier or later surveys.

1.1. Pasture-based versus conventional dairy systems

Among pasture-based operations, a broad spectrum of degree of dependence on pasture exists, with Taylor and Foltz (2006) breaking this group into "management intensive grazing" and "mixed feed" operations. Management-intensive grazers use pasture as the primary forage source during the grazing period, while mixed feed operators obtain part of their forage rations from pasture but rely primarily on stored feed. In selecting a sample of Pennsylvania dairy farms for a survey of grazers, Hanson et al. (2004) required that the animals had to obtain at least 40% of their forage needs during the summer months from pasture. Dartt et al. (1999) defined a "management intensive grazing operation" as one where at least 25% of the annual forage requirement was obtained via pasture. The animals were to have been grazed for at least four months. Thus, the actual percentage of pasture required for an operation to be legitimately termed "pasture-based" seems to vary depending upon the assumptions of those conducting the studies.

Pasture-based production varies by region, as forage availability from pasture depends partially upon climate. In the United States, the grazing season may range from 4–5 months in the Upper Midwest to year-round in the Southeast. For the current study, operations (based on grazing season data) are categorized as either: (1) Conventional, meaning that either no pasture is used or less than 25% of forage needs are met by pasture during the grazing season, or (2) Pasture-based, meaning that $\geq$25% of forage needs are met by pasture during the grazing season.

Pasture-based dairying has gained attention in the United States in recent years. Several positive attributes of pasture-based dairying are generally cited as reasons to consider it: (1) it is less damaging to the environment; (2) animal welfare is improved, as animals are confined for shorter periods; (3) pasture-based operators are generally happier with their lifestyle (Taylor and Foltz, 2006); and (4) if well managed, pasture-based production can be competitive with conventional production, as lower milk production is offset by lower production costs. Furthermore, growth of organic milk demand and supply has increased recently and USDA organic rules require dairy animals to have access to pasture (though rules on degree of access to pasture with dairy operations are currently being considered).

Though today's definition and practice of organic milk production is relatively "new," pasture-based technology is not, as pasture-based systems can be argued to have been the traditional system. Pasture-based dairying remains the most common production technology used in several subregions of the southeastern United States, as well as in New Zealand and Ireland. Verkerk (2003) provides an extensive review of the state of the New Zealand dairy industry, discussing the challenges of pasture-based production, including the need to breed over a short time period and the difficulties associated with applying embryo technologies. Thus, while pasture-based production is generally lower-cost, there are significant challenges associated with the adoption of other cost-reducing technologies.

A number of studies have been conducted on the economics of pasture-based versus conventional dairy production. Those that have conducted analyses based upon experiment station trials, holding farm size constant, have included Rust et al. (1995) in Minnesota; Tucker et al. (2001) in Mississippi; White et al. (2002) in North Carolina; and Tozer et al. (2003) in Pennsylvania. The Minnesota and Mississippi studies found pasture-based systems to economically outperform conventional systems; the North Carolina study found that pasture-based systems could be competitive with conventional systems under certain conditions; and the Pennsylvania study found higher economic performance with conventional systems. Analyses using simulation or linked spreadsheet analyses have included Parker et al. (1992) in Pennsylvania; Elbehri and Ford (1995) in Pennsylvania; and Soder and Rotz (2001) in Pennsylvania; all of which found favorable economic performance of pasture-based relative to conventional farms. A third category of studies has compared the systems based upon farm survey results: Hanson et al. (2004) in Pennsylvania and Dartt et al. (1999) in Michigan, both of which found favorable economic performance of pasture-based relative to conventional farms.

Several observations are made with respect to previous studies conducted on the economics of pasture-based versus conventional dairy production. First, the studies have been experimental in nature, have used simulation techniques, or have resulted from surveys of relatively small numbers of small farms in specific regions. Analyses have generally compared relatively small conventional farms with relatively small pasture-based operations, with none fully addressing the increasingly common 250+ cow operation. Few farms in that size category are pasture-based, as the land requirement and costs associated with assembling cows for milking becomes prohibitive. With the emergence of much larger-scale operations, the majority of which are likely to be conventional, it is of use to compare efficiencies that cover the full range of operation sizes. In order to survive economically, smaller, nonorganic pasture-based operations will need to remain competitive with larger, conventional operations.

2. Data and methods

This study uses data from the Agricultural Resource Management Survey (ARMS), conducted by USDA's National Agricultural Statistics Service and Economic Research Service. Over 2003–2007, this dataset provides close to 150,000 dairy farms in the survey design. The survey collected information on farm size, type, and structure; income and expenses; production practices; and farm and household characteristics, resulting in a rich database for analysis. Because this design-based survey uses stratified sampling, the dataset contains expansion factors (weights) for each observation that can be used to extend the results to the U.S. farm population.

2.1. A model to assess technical and scale efficiency

A parametric input distance function approach is used to estimate performance measures, including returns to scale (RTS) and technical efficiency (TE). The input distance function is denoted as $D^I(\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{R})$, where $\boldsymbol{X}$ refers to inputs, $\boldsymbol{Y}$ to outputs, and $\boldsymbol{R}$ to other farm efficiency determinants. For the analyses, two outputs developed from the ARMS data for dairy farms are: Y_{CROP} = value of crop production and Y_{LIVE} = value of livestock production. Inputs are: X_{LAB} = labor; X_{CAP} = capital; X_{MISC} = miscellaneous including feed, fertilizer, and fuel; and X_{OLND} = land.

Estimating $D^I(\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{R})$ requires imposing linear homogeneity in input levels (Färe and Primont, 1995), which is accomplished through normalization (Lovell et al., 1994); $D^I(\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{R})/X_1 = D^I(\boldsymbol{X}/X_1, \boldsymbol{Y}, \boldsymbol{R}) = D^I(\boldsymbol{X}^*, \boldsymbol{Y}, \boldsymbol{R})$.[1] Approximating this function by a translog functional form to limit *a priori* restrictions on the relationships among its arguments results in

$$
\begin{aligned}
\ln D^I_{it}/X_{1,it} = {} & \alpha_0 + \sum_m \alpha_m \ln X^*_{mit} \\
& + .5 \sum_m \sum_n \alpha_{mn} \ln X^*_{mit} \ln X^*_{nit} \\
& + \sum_k \beta_k \ln Y_{kit} + .5 \sum_k \sum_l \beta_{kl} \ln Y_{kit} \ln Y_{lit} \\
& + \sum_q \phi_q R_{qit} + .5 \sum_q \sum_r \phi_{qr} R_{qit} R_{rit} \\
& + \sum_k \sum_m \gamma_{km} \ln Y_{kit} \ln X^*_{mit} \\
& + \sum_q \sum_m \gamma_{qm} \ln R_{qit} \ln X^*_{mit} \\
& + \sum_k \sum_q \gamma_{kq} \ln Y_{kit} \ln R_{qit} + v_{it} \\
= {} & TL(\boldsymbol{X}^*, \boldsymbol{Y}, \boldsymbol{R}) + v_{it},
\end{aligned} \tag{1}
$$

or

$$
\begin{aligned}
-\ln X_{1,it} &= TL(\boldsymbol{X}^*, \boldsymbol{Y}, \boldsymbol{R}) + v_{it} - \ln D^I_{it} \\
&= TL(\boldsymbol{X}^*, \boldsymbol{Y}, \boldsymbol{R}) + v_{it} - u_{it},
\end{aligned} \tag{2}
$$

where i denotes farm; t the time period; k, l the outputs; m, n the inputs; and q, r the $\boldsymbol{R}$ variables. We specify X_{OLND} as land, so the function is specified on a per-acre basis, consistent with much of the literature on farm production in terms of yields.

The distance from the frontier, $-\ln D^I_{it}$ is explicitly characterized as the technical inefficiency error $-u_{it}$. As in Battese and Coelli (1995),[2] we use maximum likelihood (ML) methods to estimate (2) as an error components model. The one-sided error term u_{it} is a nonnegative random variable independently distributed with truncation at zero of the $N(m_{it}, \sigma_u^2)$ distribution, where $m_{it} = \boldsymbol{R}_{it}\delta$, $\boldsymbol{R}_{\mathrm{it}}$ is a vector of farm efficiency determinants (assumed here to be the factors in the $\boldsymbol{R}$ vector), and δ is a vector of estimable parameters. The random error component v_{it} is assumed to be independently and identically distributed, $N(0, \sigma_v^2)$.

This function is estimated using stochastic production frontier (SPF) techniques. Technical efficiency is characterized assuming a radial contraction of inputs to the frontier (constant input composition). The econometric model includes two error terms to represent the distance from the frontier: a random (white noise) error term, v_{it}, assumed to be normally distributed, and a one-sided error term, u_{it}, assumed to be distributed as a half normal.

The productivity impacts (marginal productive contributions, MPC) of outputs or inputs can be estimated from this model by the first order elasticities, $\mathrm{MPC}_m = -\varepsilon_{D^I, Y_m} = -\partial \ln D^I(\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{R})/\partial \ln Y_m = \varepsilon_{X_1, Y_m}$ and $\mathrm{MPC}_k = -\varepsilon_{D^I, X^*_m} = -\partial \ln D^I(\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{R})/\partial \ln X^*_k = \varepsilon_{X_1, X^*_k}$. MPC_m indicates the increase in overall input use when output expands (and so should be positive, like a marginal cost or output elasticity measure), and MPC_k indicates the shadow value (Färe and Primont, 1995) of the kth input relative to X_1 (and so should be negative, like the slope of an isoquant). Similarly, the marginal productive contributions of structural factors, including soil texture

[1] By definition, linear homogeneity implies that $D^I(\omega X, Y, R) = \omega D^I(X, Y, R)$ for any $\omega > 0$; so if ω is set arbitrarily at $1/X_1$, $D^I(X, Y, R)/X_1 = D^I(X/X_1, Y, R)$.

[2] We used Tim Coelli's FRONTIER package for the SPF estimation, and computed the measures and t-statistics for measures using PC-TSP.

(TEXT), water holding capacity (WATHCA), and urban influences as measured by Nehring et al. (2006) (URBAN), can be measured through the elasticities, $\mathrm{MPC}_{R_q} = -\varepsilon_{D^I,R_q} = -\partial \ln D^I(\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{R})/\partial R_q = \varepsilon_{X_1,R_q}$. If $\varepsilon_{X_1,R_q} < 0$, an increased R_q implies that less input is required to produce a given output, which implies enhanced productivity, and vice versa.[3]

Scale economies (SE) are calculated as the combined contribution of the M outputs Y_m, or the scale elasticity $\mathrm{SE} = -\varepsilon_{D^I,Y} = -\sum_m \partial \ln D^I(\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{R})/\partial \ln Y_m = \varepsilon_{X_1,Y}$. That is, the sum of the input elasticities, $\sum_m \partial \ln X_1/\partial \ln Y_m$, indicates the overall input–output relationship and thus returns to scale. The extent of scale economies is thus implied by the shortfall of SE from 1; if $\mathrm{SE} < 1$, inputs do not increase proportionately with output levels, implying increasing returns to scale.

Finally, technical efficiency (TE) scores are estimated as $\mathrm{TE} = \exp(-u_{it})$ using Frontier 4.1 (Battese and Coelli, 1995). The impact of changes in R_q on technical efficiency can also be measured by the corresponding δ coefficient in the inefficiency specification for $-u_{it}$.

It is assumed that the inefficiency effects are independently distributed, and u_{it} arise by truncation (at zero) of the normal distribution with mean μ_{it}, and variance σ^2, where the mean of μ_{it} is defined by

$$\mu_{It} = \delta_0 + \delta_1(\mathrm{Urban}_{it}) + \delta_2 \ln(\mathrm{Oplabor}_{it}) + \delta_3(\mathrm{Splabor}_{it}) + \delta_4(\mathrm{Totau}_{it}) + \delta_5 \ln(\mathrm{Year}_{it}). \tag{3}$$

In Eq. (3), variables are measured as follows: Urban_{it} is a measure of the impact of urbanization on agricultural activity (see Nehring et al., 2006), Oplabor and $\mathrm{Splabor}_{it}$ represent hours of operator and spouse hours worked off farm, respectively, Totau represents all livestock, and year represents the year of observation. The δ_1-parameter, measuring the effect of urbanization on the inefficiency effects in Eq. (3), is expected to have a positive sign—i.e., negative given Nehring et al.'s (2006) findings. That is, higher population pressure is negatively related to technical efficiency. The sign on the δ_2-parameter measuring operator labor is expected to be positive as operator labor off-farm pressures on farm tasks, while the sign on the δ_3-parameter measuring the impact of spouse labor is expected to be negative, as spouse labor off-farm provides extra cash to support the dairy enterprise. Evidence in Fernandez et al. (2007) suggests that operator hours worked off farm are negatively related to technical efficiency. The sign on the δ_4-parameter measuring total livestock units on the farm is expected to be negative reflecting more effective managerial input on larger operations. Finally, the sign on the δ_5-parameter measuring change in technical efficiency is expected to be negative reflecting a more technically efficient dairy industry over time.

2.2. Systems and size categories for comparison

The SPF methods are used to estimate TE associated with dairies falling into eight combinations of size and production system as defined earlier in this paper. To systematically categorize the farms into Conventional and Pasture-based systems, a binomial logit model is used. The dependent variable includes two categories describing the extent of pasture use, where Conventional corresponds to <25% of forage being obtained from pasture during the grazing season and Pasture-based corresponds to ≥25% of forage being obtained from pasture during the grazing season. Farmers were asked about their use of grazing in the 2005 ARMS dairy version that allow for this categorization. The logit model is based upon 1,814 observations. With logit model results, all 150,000 farms including dairy enterprises in the 2003–2007 ARMS can be predicted to fall into either the Conventional or Pasture-based categories. Both system categories can then be further sorted into the size categories.

When cross-sectional analysis is used for prediction purposes in time-series analysis, several concerns arise. Parikh and Edwards (1980) discuss issues to be satisfied for validity of this type of analysis: (1) independent variables should lend themselves to "easy prediction." In our case, 16 independent variables are included in all five years of the 2003–2007 data, so easy predictions can be made. (2) Coefficient estimates should be intertemporally stable. This implies correct prediction of a particular farm based upon coefficient estimates should be the same in any of the years 2003–2007 as in the ARMS dairy version, 2005. Major structural change cannot have occurred over the period of prediction such that the coefficient estimates would change over time. Our selection of only two years prior to and after 2005 minimizes concerns that might arise due to this issue. Likewise, independent variables included in the logit model were selected with this in mind, selecting those expected to be relatively stable. Finally, (3) coefficient estimates should adequately predict the dependent variable, so that goodness of fit is acceptable. In the case of a logit model, this suggests that the percentage correctly predicted or the percentage concordant should be acceptable. In forecasting commodity imports over a 7-year period, Parikh and Edwards (1980) found that cross-sectional analysis to be a reasonable predictor.

Independent variables in the logit analysis include eight regions of the U.S.: the NORTHEAST, LAKE STATES, CORN BELT, APPALACHIA, SOUTHEAST, SOUTHERN PLAINS, MOUNTAIN WEST, and PACIFIC (with regions defined as in Footnote 4 and LAKE STATES serving as the base)[4]; number of milk cows (COWS); farmer age (AGE); pasture acres

[3] Note that a standard "productivity" or "technical change" measure, usually defined as the elasticity with respect to time, or the time trend of the input-output relationship, is not targeted here. Elasticities with respect to the time dummies provide indications of production frontier shifts for each time period, but for short time series other external factors such as weather often confound estimation of a real technical change trend.

[4] States and their designated regions included in this dataset include: NORTHEAST: ME, NY, PA, VT; LAKE STATES: MI, MN, WI; CORN BELT: IL, IN, IA, MO, OH; APPALACHIA: KY, TN, VA; SOUTHEAST: FL, GA; SOUTHERN PLAINS: TX; MOUNTAIN WEST: AZ, ID, NM; and PACIFIC: CA, OR, WA.

Table 1
Logit results for choice of production system, $n = 1{,}726$

Variable	Beta	t-statistic
Constant	−0.8709	−0.9038
Lake States	1.1525***	2.6243
Corn Belt	−0.2606	−0.5164
Appalachia	1.6635***	4.8027
Southeast	3.0587***	3.5296
Southern Plains	1.4266**	2.5052
Mountain West	−1.8081***	−3.2243
Pacific	0.6885	1.2848
Cows	−0.0013***	−3.6256
Age	0.0112	1.0202
Pasture	0.4737***	2.7069
Labor	0.0012***	3.0025
Machinery	−0.0014**	−2.3713
Feed	0.1090	0.0688
Silage	−1.3891*	−1.6876
Hay	0.5553	1.1631
Alfalfa	0.6011**	1.9926
Percentage Correctly Predicted: 76.6%	Percentage Discordant: 17.1%	
Percentage Concordant: 82.8%	Percentage Tied: 0.1%	

Notes: ***Significance at the 1% level ($t = 2.576$). **Significance at the 5% level ($t = 1.96$). *Significance at the 10% level ($t = 1.645$). The t-tests are estimated using design standard errors using the delete-a-group jackknife estimation procedure, with 15 replicates.

per cow (PASTURE); labor hours per cow (LABOR); machinery expenses per cow (MACHINERY); percentage of farm expenses for feed (FEED); and percentage of farm acres in silage (SILAGE), hay (HAY), and alfalfa (ALFALFA).[5]

3. Results

Examination of data in Table 1 suggests a number of variables are significant in predicting system choice. The percentage correctly predicted is 76% and the percentage concordant is 83%, suggesting a relatively good fit for prediction purposes. Region influenced system choice, as did number of milk cows, pasture acres per cow, labor hours per cow, machinery expenses per cow, and percentage of farm acres in silage and alfalfa.

Examining the Table A.1, which presents sorts by system and size category, the highest percentage of value of production was from the largest conventional dairies, followed by the largest category of pasture-based dairies. The smallest percentage of value of production was from the smallest conventional size category. Looking across the size categories by system, it is noted that there is an average of 46 cows per farm on both the pasture-based and conventional $\leq$50 cow categories, and 76 cows per farm on both the pasture-based and conventional $50 <$ cows ≤ 100 cow categories, making those categories consistent in size and, thus, lending themselves particularly well to direct comparisons by system.

A number of financial measures can be examined for farm size and system choice. Gross return on assets and net return on assets are highest for the largest size category of conventional dairy farms; all other categories did not differ significantly from one another on net return on assets. Variable costs per cow were lowest for the largest pasture-based and conventional dairies, showing the impact of both system choice and size on cost of production. Breaking this down by category, two costs are particularly interesting: both labor costs and machinery costs per cow are reduced dramatically as farm size increases; machinery costs per cow are generally higher for conventional systems. Despite having lower variable costs, the larger conventional farms were located on much higher-priced land than were the smaller pasture-based and conventional farms.

Debt-asset ratios were higher for conventional farms, and increased with farm size. The largest farms were much more highly leveraged than the small farms. Technical efficiency also increased with size, with the smallest pasture-based and conventional dairy farms having technical efficiency scores of 0.68 and 0.74, respectively, and the largest pasture-based and conventional dairy farms with technical efficiency scores of 0.81. Returns to scale increased with farm size, with the largest conventional dairy farms realizing the greatest returns to scale.

Fig. 1 shows the percentages of farms with positive household net returns and net worth using several assumptions. It is clear that lower percentages of farms in the small and medium-sized categories using both systems had lower economic returns, and the 51–100 cow size classes had lower percentages with positive net returns per cow. Percentages of farms with positive returns over operating expenses increased with size among pasture-based farms. With the exception of the small conventional farms, farms with larger herds had greater net worth. These results show visually the impact of farm size and system on the realization of positive net return and net worth, but also show that some farms in all size categories are competitive. It is noted from Table A.1 that smaller farms, especially conventional ones, were more diversified in the sense that the value of dairy products divided by value of total production on the farm was smaller on the small farms. This would generally serve to inflate the net returns for the smaller farms.

3.1. *Stochastic frontier results*

More than one-half of the estimated coefficients from the input distance function are significant in the pooled, conventional, and pasture-based system runs as shown in Table 2,

[5] A number of these variables can be hypothesized to be potentially endogenous, or correlated with the error term. This would suggest that their resulting estimates are biased. In the context of the design-based ARMS survey and associated use of the delete-a-group jackknife estimator, traditional means of testing for endogeneity are invalid. Traditional treatment of endogeneity involves development of instrumental variables through first stage equations and inclusion of predicted values in the main equation. Previous inclusion of instrumental variables was found to severely reduce predictive power, especially percentage correctly predicted. Since our objective is strong out-of-sample predictive power rather than insurance of unbiased estimates for each coefficient, we have opted against treatment of these variables as endogenous.

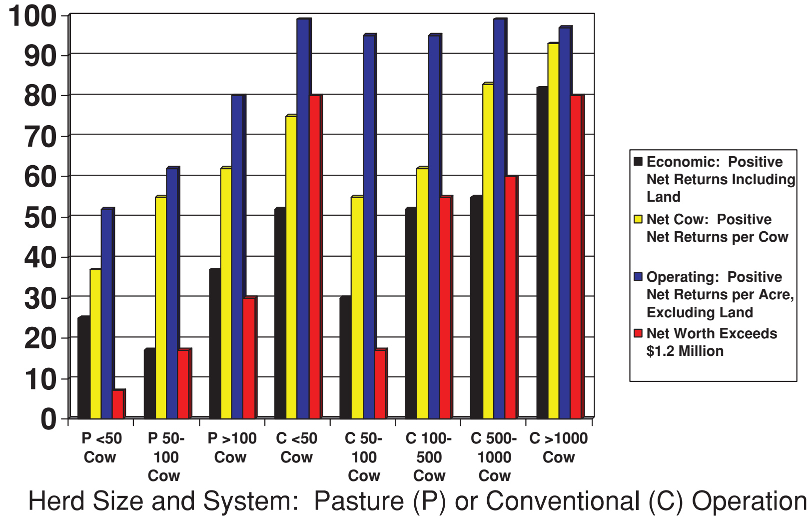

Fig. 1. Percentage of dairy households with positive net returns and wealth levels by class: *some farms are competitive in all classes*.

Table 2
Input distance function parameter estimates, 2003–2007 dairy

Variable	Parameter *t*-test pooled	Parameter *t*-test conventional	Parameter *t*-test pasture based
α_{θ}	12.254 (8.11)***	8.368 (8.17)***	11.355 (2.46)**
α_{XLAB}	−0.516 (−28.14)***	−0.444 (−62.74)***	−0.575 (−18.58)***
α_{XFEED}	−0.110 (−9.16)**	−0.104 (−5.39)***	−0.097 (−7.47)***
α_{XCAP}	−0.214 (−10.85)***	−0.211 (−10.30)***	−0.203 (−5.57)***
β_{YCROP}	0.015 (0.46)	0.070 (4.64) ***	0.034 (0.55)
β_{YLIVE}	−0.628 (−2.65)**	−0.104 (−0.57)	−0.463 (−0.62)
$\beta_{YCROP,YCROP}$	0.006 (7.80)***	0.012	0.007 (2.70)**
$\beta_{YLIVE,YLIVE}$	0.048 (5.61)***	0.033 (4.30)***	0.040 (1.32)
$\beta_{YCROP,YLIVE}$	−0.009 (−3.38)***	−0.016 (−20.17)***	−0.010 (−1.66)
$\gamma_{YLIVE,TEXT}$	0.001 (0.19)	−0.002 (−0.37)	0.002 (0.39)
$\gamma_{YLIVE,WATHC}$	−0.003 (−1.32)	−0.004 (−2.09)*	−0.001 (−0.26)
$\gamma_{YCrop,Urban}$	0.002 (0.99)	0.007 (4.00)***	0.006 (1.34)
$\alpha_{XLAB,XLAB}$	0.120 (16.79)***	0.090 (35.12)***	0.138 (18.09)***
$\alpha_{XFEED,XFEED}$	−0.012 (−1.28)	−0.032 (−1.26)	−0.007 (−0.64)
$\alpha_{XCAP,XCAP}$	−0.021 (−2.43)**	0.009 (1.17)	−0.026 (−2.73)**
$\alpha_{XLAB,XFEED}$	−0.056 (−3.19)	−0.001 (−0.04)	−0.066 (−5.96)***
$\alpha_{XLAB,XCAP}$	−0.052 (−2.66)	−0.094 (−17.03)***	−0.052 (−1.89)*
$\alpha_{XFEED,XCAP}$	0.021 (2.30)**	0.003 (0.11)	0.025 (1.91)*
$\alpha_{XPassive\ In}$	0.015 (0.52)	−0.055 (−2.45)**	0.045 (2.76)**
α_{XSMALL}	0.005 (0.07)	−0.086 (−2.92)***	0.031 (0.43)
$\alpha_{XMEDIUM}$	0.063 (0.70)	−0.109 (−3.54)***	0.106 (1.39)
α_{XLARGE}	0.130 (1.23)	−0.099 (−1.68)	0.207 (2.19)**
α_{XYear}	−0.145 (−8.42)***	−0.126 (−5.23)***	−0.141 (−8.74)***
δ_{INEFF}	−1.265 (−0.31)	−7.659 (−1.45)	−0.029 (−0.00)
δ_{Urban}	0.264 (0.19)	−0.012 (−0.04)	0.271 (0.30)
$\delta_{Oplabor}$	0.500 (2.36)**	−0.350 (−0.92)	0.442 (20.06)***
$\delta_{Splabor}$	−0.274 (−2.55)**	−0.258 (−7.58)***	−0.223 (−1.35)
δ_{Totau}	0.008 (0.80)	−0.260 (−1.05)	0.0588 (0.737)
δ_{Year}	−1.112 (−2.61)**	0.371 (1.92)*	−1.119 (−4.47)***
δ^2	1.909 (3.32)***	1.916 (0.92)	1.449 (4.99)***
γ	0.935 (42.90)***	0.957 (25.00)***	0.915 (42.28)***
Log-	−14,978.24	−31,258.86	−21,140.18
Eff	0.786	0.779	0.800
RTS	0.560	0.650	0.441

Notes: ***significance at the 1% level ($t = 2.977$), **significance at the 5% level ($t = 2.145$), and *significance at the 10% level ($t = 1.761$).
Source: ARMS, USDA (2003–2007). The *t*-statistics are based on 8,263 observations for the pooled sample, 3,371 for the conventional sample, and 4,892 for the pasture-based sample, using weighting techniques described in Dubman (2000).

Table 3
MPC's for outputs and inputs (*t*-statistics in parentheses)

MPC_{YCROP}	0.031	(9.82)***	MPC_{XLAB}	−0.293	(−2.30)**
MPC_{YLIVE}	0.532	(4.25)***	MPC_{XFEED}	−0.176	(−2.25)**
			MPC_{XCAP}	−0.225	(−1.82)*
			MPC_{XOLND}	−0.323	(−2.94)***

Notes: ***significance at the 1% level ($t = 2.977$), **significance at the 5% level ($t = 2.145$), *significance at the 10% level ($t = 1.761$).
Source: USDA ARMS (2003–2007). The *t*-statistics are based on 8,263 observations using weighting techniques described in Dubman (2000)'s CV15 program.

including the own prices on labor, miscellaneous, and capital, and the cross-price effects on livestock and crops. All of the measures of outputs and inputs have the expected signs for the pooled, conventional, and pasture-based groups, positive for outputs and negative for inputs, as shown in Tables 3 and 4. For the pasture-based run, only one marginal contribution is significant—that for livestock. Results in Table 4 suggest that conventional and pasture-based systems are represented by separate technologies, as can be seen from differences in the marginal contributions and various other forage intensity variables. The "own-technology" (separate runs by production system) results are compared to a "pooled" SPF, which assumes that the technology is common to all dairies in the sample. Accounting for technological differences among the systems reveals, among other things, that opportunities to improve scale economies are much greater in the pasture-based system than indicated by the pooled data.

4. Conclusions

The logit model allowed for sorting of farms into two general dairy farm systems. Evidence from Table A.1 and Table 4 suggests that farmers under each of the systems are producing under different technologies: the systems differ significantly by size, productivity, and other measures. Therefore, in order to examine small-farm competitiveness, one needs to compare by system.

The overall conclusion is that, in terms of economic viability, size of operation matters. Large conventional farms economically outperformed smaller farms in most system categories: gross return on assets, net return on assets, variable costs per cow, labor costs per cow, machinery costs per cow, and technical efficiency. Pasture-based dairies with ≥100 cows were competitive with the largest conventional dairies using several economic measures: variable costs per cow and machinery costs per cow. The largest conventional farms were much more highly leveraged than were farms in all other size categories. Higher percentages of farm households realized positive net returns in the larger than in the smaller size categories.

Regardless of system, the dairy farms with ≤50 cows were noncompetitive with larger farms in terms of gross return on assets, net return on assets, variable costs per cow, labor costs per cow, and machinery costs per cow. This suggests that, on average, small farms are noncompetitive with large farms in the U.S. dairy industry. It is, however, noted that some small farms in all size/system classes realized positive net returns, and were, thus, competitive.

Table 4
Comparison of technical information and marginal contributions by predicted category in the pooled and own technology estimates, 2005 dairy

Item	Pasture pooled	Pasture own tech results	Conventional pooled	Conventional own tech results
Number of observations	4,892		3,371	
Number of farms	195,835		57,182	
Percentage of farms	77.4		22.6	
Percentage of value of production	38.0		62.0	
Number of cows per farm	144^{B}		526^{A}	
Milk per cow (lbs. annually—2005)	$16{,}338^{B}$		$19{,}656^{A}$	
Efficiency score	0.785	0.797	0.794	0.778
Returns to scale	0.53^{B}	0.44*	0.65^{A}	0.65**
MPC_{YCROP}	0.031^{B}	0.007	0.056^{A}	0.034**
MPC_{YLIVE}	0.515^{B}	0.438*	0.614^{A}	0.621***
MPC_{XLAB}	-0.266^{B}	−0.289	-0.412^{A}	−0.333***
MPC_{XFEED}	-0.360^{B}	−0.179	-0.156^{A}	−0.135***
MPC_{XCAP}	−0.076	0.192	−0.220	−0.268
MPC_{XOLND}	-0.352^{B}	−0.339	-0.221^{A}	−0.284***
Forage Intensity Variables				
Total Animal Units per crop ace	0.69^{B}		1.15^{A}	
Dairy pasture acres/cow	0.87^{B}		0.01^{A}	
Corn silage acres/acres har	0.14^{B}		0.22^{A}	
Total hay acres/acres harvested	0.56^{B}		0.26^{A}	
Fertilizer cost per crop acre ($)	36.68^{B}		52.15^{A}	
Pesticide cost per crop acre ($)	11.72^{B}		25.46^{A}	

Notes: Superscript A indicates significantly different from pasture-based; B indicates significantly different from conventional at the 10% level. ***indicates significance at the 1% level, **significance at the 5% level, and *significance at the 10% level.
Source: Authors' analysis of USDA ARMS (2003–2007). The *t*-statistics are based on 8,263 observations using weighting techniques described in Dubman (2000).

Appendix

Table A.1
Cost and production means and statistics by pasture intensity and herd size, 2003–2007

Item	Pasture-based ≤50 Cows	Pasture-based 50 < Cows ≤ 100	Pasture-based ≥100 Cows	Conventional ≤50 Cows	Conventional 50 < Cows ≤ 100	Conventional 100 < Cows ≤ 500	Conventional 500 < Cows ≤ 1,000	Conventional >1,000 Cows
Number of observations	295	1,327	3,270	35	228	1,603	784	721
Percentage of farms	7.9	33.2	36.4	0.3	3.9	12.9	2.7	2.2
Percentage of value of prod.	1.4	9.6	26.9	0.1	1.9	15.4	9.8	34.7
Dairy cows per farm	45.9^{BCEGH}	76.0^{ACDFGH}	226.3^{ABDFGH}	45.9^{BCFGH}	76.4^{ACDFGH}	216.9^{ABDEGH}	$689.0^{ABCDEGH}$	$2,465.4^{ABCDEFG}$
Acres operated	158.0^{BCEGH}	238.0^{ACFGH}	$451.6^{ABDEFGH}$	196.7^{CFGH}	219.2^{ACFGH}	$516.0^{ABCDEGH}$	$824.5^{ABCDEFH}$	$1,143.8^{ABCDEFG}$
Gross return on assets (%)	13.0^{BCEFGH}	17.1^{ACEFGH}	23.7^{ABFGH}	17.6^{FGH}	23.8^{ABFGH}	$29.6^{ABCDEGH}$	38.9^{ABCDFH}	48.2^{ABCDFG}
Net return on assets (%)	5.2^{H}	5.2^{H}	5.8^{H}	4.0^{H}	4.4^{H}	5.9^{H}	5.7^{H}	$8.9^{ABCDEFG}$
Portion of total value prod'n from dairy	0.791^{GH}	0.817^{FGH}	0.832^{FH}	0.705^{GH}	0.694^{GH}	0.769^{BCGH}	0.870^{ABDEF}	0.908^{ABCDEF}
Variable costs per cow ($)	$1,529^{BFGH}$	$1,292^{CDFGH}$	$764^{ABDEFGH}$	$1,647^{BFGH}$	$1,407^{CGH}$	$1,151^{ABCDGH}$	$1,056^{ABCDEFH}$	$926^{ABCDEFG}$
Labor costs per cow ($)	$1,146.6^{BCDEFGH}$	714.9^{ACDFGH}	320.5^{ABDEGH}	$601.2^{ABDEFGH}$	748.2^{ACDFGH}	345.7^{ABDGEH}	$255.0^{ABCDEFH}$	$165.0^{ABCDEFG}$
Machinery costs per cow ($)	188.5^{DEF}	197.4^{CDEFG}	150.7^{BDEFG}	596.9^{ABCFGH}	428.8^{ABCGH}	303.3^{ABCDGH}	240.0^{BCDEFH}	165.4^{DEFG}
Returns to scale	0.47^{BCDFGH}	$0.50^{ACDEFGH}$	0.58^{ABDFGH}	0.54^{ABCFGH}	0.54^{ABCFGH}	$0.64^{ABCDEGH}$	$0.74^{ABCDEFH}$	$0.81^{ABCDEFG}$
Efficiency score	$0.68^{BCDEFGH}$	0.78^{ACGH}	0.81^{ABDEF}	0.74^{CGH}	0.75^{CFGH}	0.80^{ACE}	0.81^{ABDE}	0.81^{ABDE}
Forage Intensity								
Totau/harvested acre	0.66^{GH}	0.61^{CGHJ}	0.72^{BFGH}	0.55^{GH}	0.64^{GH}	0.63^{CGH}	$1.01^{ABCDEFH}$	$2.60^{ABCDEFG}$
Manure *N* per acre op. (lbs.)	42^{GH}	39^{GH}	47^{BFGH}	35^{GH}	41^{GH}	40^{CGH}	$65^{ABCDEFH}$	$168^{ABCDEFG}$
Fertilizer exp acre op. ($)	$26^{ECDEFGH}$	32^{ACEFGH}	40^{ABFFGH}	41^{AGH}	46^{ABCGH}	48^{EABCGH}	59^{ABCDEF}	58^{ABCDEF}
Land price per acre	$2,308^{EFGH}$	$2,456^{EFGH}$	$2,502^{EFGH}$	$2,757^{GH}$	$3,375^{ABCH}$	$3,174^{ABCGH}$	$4,081^{ABCDEF}$	$4,914^{ABCDEF}$
Debt-asset ratio	0.09^{CDEFGH}	0.12^{CFGH}	0.14^{ABFGH}	0.18^{AH}	0.18^{AH}	0.19^{ABCGH}	0.23^{ABCFH}	$0.31^{ABCDEFG}$

Source: Authors' analysis of USDA Agricultural Resource Management Surveys USDA (2003–2007). a. The *t*-statistics are based on 8,263 observations using weighting techniques described in Dubman (2000). A through J indicate significant differences in means across columns with A = Pasture dairy ≤ 50, B = 50 < Pasture dairy ≤ 100, C = Pasture dairy > 100, D = Conventional dairy ≤ 50, E = 50 < Conventional dairy ≤ 100, F = 100 < Conventional dairy < = 500, G = 500 < Conventional dairy ≤ 1,000, H = Conventional dairy > 1,000.

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